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640 Gbit/s Optical Time-Division Add-Drop Multiplexing in a Non-Linear Optical Loop Mirror

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***Abstract*—Error-free 640 Gbit/s all-optical time-division add-drop multiplexing is demonstrated using a non-linear optical loop mirror. Both the add- and drop operations are achieved simultaneously by switching.**

I. Introduction

Time-division add-drop multiplexing (TADM) consists in extracting and replacing the individual data pulses in a serial data signal. This is an important networking functionality in the context of optical time-division multiplexed (OTDM) systems. OTDM data signals are formed by bit-interleaving narrow-pulsed, identical-wavelength data channels at a low base rate (e.g. 10 Gbit/s), enabling aggregate bit rates currently up to 640 Gbit/s. Fibre-based switches are very promising candidates for TADM up to 640 Gbit/s, since they are based on the non-linear Kerr effect which has an ultra-fast femtosecond response. Earlier, error-free fibre-based TADM has been demonstrated at 160 Gbit/s using a Kerr shutter [1] and a non-linear optical loop mirror (NOLM) [2], and recently at 640 Gbit/s using a non-linear polarisation-rotating fibre loop [3]. Previously, we have proposed a method for performing the entire TADM operation in a single step using a NOLM, by achieving both the drop- and add-operation simultaneously by cross-phase modulation (XPM) with a single control signal, and this was demonstrated at 320 Gbit/s [4]. In this paper, error-free operation at 640 Gbit/s is shown.

II. Principle and Experimental Set-up

The experimental set-up for simultaneous TADM at 640 Gbit/s using the NOLM is shown in Figure 1. The NOLM has previously been used for TADM by using the device for the drop- and clear-operations (using XPM by a control signal), followed by the addition of a new data-channel into the cleared time-slot using a (passive) coupler [5]. In this paper, the add-operation is incorporated into the NOLM by injecting the add-channel into the second (right) NOLM input port, as shown in Figure 1. A more detailed explanation of the working principle can be found in [4]. The output 640 Gbit/s data of the TADM with the added channel is demultiplexed in a standard NOLM (DEMUX) to enable detection and subsequent bit error-rate (BER) evaluation.

The data transmitter is shown in Figure 2. A 10 GHz erbium glass oscillating laser (ERGO) emits $\sim$ 2 ps pulses

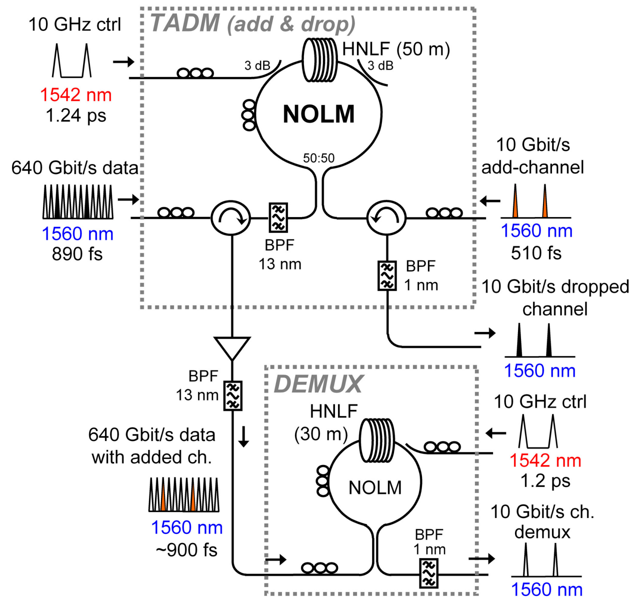

Fig. 1. Experimental set-up for 640 Gbit/s TADM with simultaneous add- and drop-operations using the NOLM (BPF: optical band-pass filter).

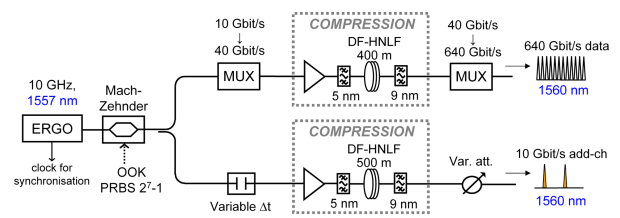

Fig. 2. Transmitter of 640 Gbit/s OTDM data and the 10 Gbit/s add-channel. The generated signals are directed to the set-up as shown in Figure 1.

at $\lambda_{data} = 1557$ nm, which are data-modulated by on-off keying (OOK) with a $2^7 - 1$ PRBS pattern. The resulting 10 Gbit/s pulses are split and used to obtain both the 640 Gbit/s data and the 10 Gbit/s add-channel. The 640 Gbit/s data are generated using $2^7 - 1$ PRBS maintaining delay-line multiplexer stages (MUX). The pulse compressors are based on chirping and spectral broadening by self-phase modulation

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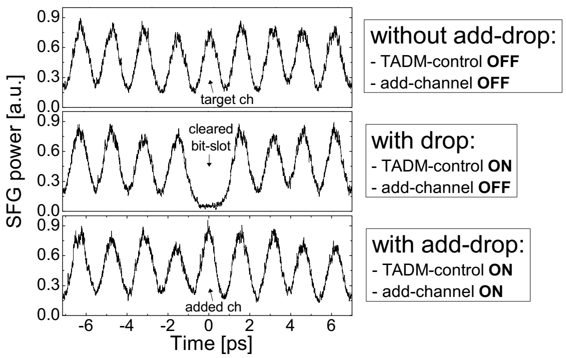

Fig. 3. Cross-correlations of the 640 Gbit/s data at the output of the TADM.

in a (negative) dispersion-flattened highly non-linear fibre (DF-HNLF), followed by off-carrier filtering. The control pulses for the TADM and DEMUX are obtained from another 10 GHz ERGO laser at $\lambda_{ctrl} = 1542$ nm (not shown). The full-width at half maximum (FWHM) pulse widths at the input to the HNLF in the NOLM (TADM) are noted in Figure 1. The 50 m HNLF in the TADM has non-linear coefficient $\gamma = 10.5$ $W^{-1}km^{-1}$, zero-dispersion wavelength $\lambda_0 \sim 1552$ nm and dispersion slope 0.018 ps·nm^{-2}km^{-1} at 1550 nm. The 30 m HNLF in the NOLM (DEMUX) has similar characteristics.

III. Results

The simultaneous TADM operation of the NOLM at 640 Gbit/s is successful with error-free performance. The cross-correlations of the 640 Gbit/s data in Figure 3 show that the NOLM (TADM) is able to successfully clear the target time-slot (middle trace), and switch the add-channel into the cleared time-slot with the correct timing and amplitude (bottom trace). The BER measurements of the dropped channel are shown in Figure 4 (a). When the add-channel is off, the sensitivity is -31.3 dBm. There is a penalty of 4.4 dB compared to the sensitivity of -35.7 dBm obtained when the add-channel is on, which is due to unsuppressed add-channel light leading to interferometric cross-talk. The BER curve of the added channel after demultiplexing is shown in Figure 4 (b). The sensitivity is -33.0 dBm, which is an improvement of 1.2 dB compared to the original target channel sensitivity of -31.8 dBm. This effect is partly attributed to the slightly wide TADM control pulse FWHM of 1.24 ps compared to the $\sim$ 1.56 ps time slot at 640 Gbit/s. The control pulses therefore suppress the tails of the neighbouring pulses to the target channel, resulting in a broader effective time-slot for the added channel. Figure 4 (c) shows the sensitivities of the demultiplexed target/added channel as well as 6 neighbour channels, both with and without add-drop operation. Error-free performance is obtained in all cases, but add-drop induced penalties can be observed on the nearest add-channel neigbours. This is attributed to a deterioration caused by the wide TADM control pulses, as discussed above. In general, an unstable BER performance was observed during add-drop operation (compared to w/o add-drop), which is mainly attributed to unsuppressed TADM-control light overlapping with the data spectrum. Better stability and smaller add-drop penalties are expected by using optimised control pulses and improved filtering.

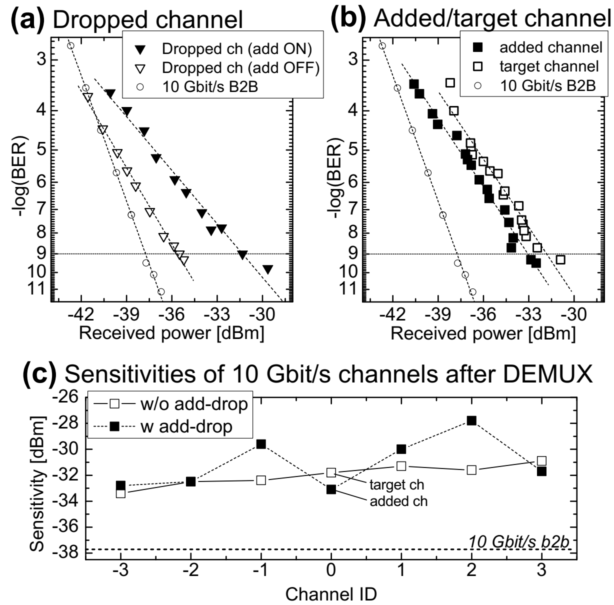

Fig. 4. Results. BER curves of: (a) dropped channel with add-ch on/off, (b) target/added channel after DEMUX. (c) Sensitivities of demultiplexed channels (sensitivity is received power for BER$= 10^{-9}$).

IV. Conclusion

Error-free 640 Gbit/s TADM with simultaneous add- and drop-operations was demonstrated using a NOLM with 50 m HNLF. The add-operation is performed with a negative penalty of -1.2 dB, but some deterioration is observed on the neighbour channels and the dropped channel. Improved results are expected using optimised control pulses and filtering.

References

[1] C. Schubert, C. Schmidt-Langhorst, K. Schulze, V. Marembert, and H. G. Weber, "Time division add-drop multiplexing up to 320 Gbit/s," in *Technical Digest Optical Fiber Communication Conference, OFC'05*, Anaheim, California, U.S.A., Mar. 2005, paper OThN2.

[2] E. J. M. Verdurmen, J. P. Turkiewicz, E. Tangdiongga, G. D. Khoe, and H. de Waardt, "Towards all-optical 320 Gb/s add-drop multiplexing using a nonlinear optical loop mirror," in *Proceedings European Conference on Optical Communication, ECOC'05*, Glasgow, Scotland, Sep. 2005, paper Th3.1.7.

[3] H. C. H. Mulvad, M. Galili, L. Grüner-Nielsen, L. K. Oxenløwe, A. T. Clausen, and P. Jeppesen, "640 Gbit/s time-division add-drop multiplexing using a non-linear polarisation-rotating fibre loop," in *Proceedings European Conference on Optical Communication, ECOC'08*, Brussels, Belgium, Sep. 2008, paper Tu.3.D.6.

[4] H. C. H. Mulvad, L. K. Oxenløwe, A. T. Clausen, M. Galili, L. Grüner-Nielsen, and P. Jeppesen, "Error-free 320 Gb/s simultaneous add-drop multiplexing," in *Technical Digest Optical Fiber Communication Conference, OFC'07*, Anaheim, California, U.S.A., Mar. 2007, paper OTuI5.

[5] J. H. Lee, T. Tanemura, Y. Takushima, and K. Kikuchi, "All-optical 80-Gb/s add-drop multiplexer using fiber-based nonlinear optical loop mirror," *IEEE Photonics Technology Letters*, vol. 17, no. 4, pp. 840–842, 2005.